A FIRST LOOK AT CALIOP/CALIPSO CLOUD ICE WATER CONTENT

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ABSTRACT

The Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) Mission will release Version 3 (V3) of its Level 2 data products during the spring of 2010. Cloud ice water content (IWC) is a featured new geophysical parameter offered at 60 m vertical resolution in the 5-km cloud profile product. IWC is calculated using a parameterization of the optical extinction at 532 nm as retrieved by the Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP). Currently this temperature-independent IWC parameterization is a beta/provisional data product, with evaluation and validation efforts underway. Preliminary results show that CALIOP IWC amounts are physically reasonable, and that the high vertical resolution and sensitivity to IWC < 0.010 gm^{-3} provides a unique picture of cloud morphology. Statistical attributes of CALIOP V3 IWC are shown for global data during August, 2007. We also evaluate IWC distributions as a function of ambient temperature, and discuss cloud particle phase and orientation. Preliminary evaluation of CALIOP/CALIPSO V3 IWC suggests that it will prove to be most accurate between 0.001-0.200 gm^{-3} for randomly-oriented ice cloud particles (ROI), corresponding to retrieved extinctions of 0.07-5.3 km^{-1}. Comparisons with IWC data from other satellite instruments have been initiated as the next step in the validation process.

1. INTRODUCTION

The effect of clouds on the Earth's atmospheric radiation budget is one of the primary uncertainties in characterizing climate change. Knowledge of the condensed water content of ice clouds is fundamental to understanding cloud physics and radiative properties [1]. The Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) team is releasing a new high-resolution IWC data set that will help to reduce this aspect of climate uncertainty.

The spring, 2010 CALIOP Version 3 (V3) release of Level 2 data includes IWC at 60-m vertical resolution in the 5-km cloud profile set of data products. An overview of the CALIOP data products and data processing algorithms is available in Winker [2] and Vaughan [3]. Clouds are discriminated from aerosol measurements in the CALIOP data set [4], and then 532 nm extinction by clouds is retrieved from CALIOP attenuated backscatter [5]. Cloud ice water content is calculated as a parameterized function of the extinction:

$$IWC = C^{0}\left(\frac{\sigma}{1000}\right)^{C^{1}} \qquad (1)$$

Here, σ is the 532 nm volume extinction coefficient in km^{-1}, and c^0 = 119 gm^{-3} and c^1 = 1.22 are coefficients derived from an observed empirical relationship between lidar extinction and an extensive set of *in situ* measurements of cloud particle properties from numerous field campaigns [6].

2. SAMPLE DATA FROM AUGUST, 2007

Cloud ice water content depends on temperature, a macrophysical quantity, and cloud particle size distribution, a microphysical quantity [1],[6]. A two-dimensional probability distribution of CALIOP IWC as a function of temperature for August, 2007 is shown in Figure 1 for constrained retrievals where direct measurement of cloud optical depth can be obtained using two-way transmittance [5].

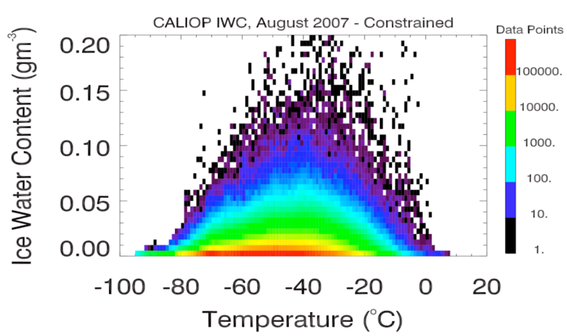

Figure 1. Two-dimensional probability distribution of constrained retrievals of CALIOP IWC in ice clouds for all latitudes and all altitudes during August, 2007.

IWC is expected to vary by location in a cloud [5], with higher values often located towards the cloud center, and with lower IWC found at the cloud top and/or bottom. As an example of how the high-resolution lidar data can resolve internal cloud IWC distributions, Figures 2 shows CALIOP data in the tropics and subtropics on August 5, 2007.

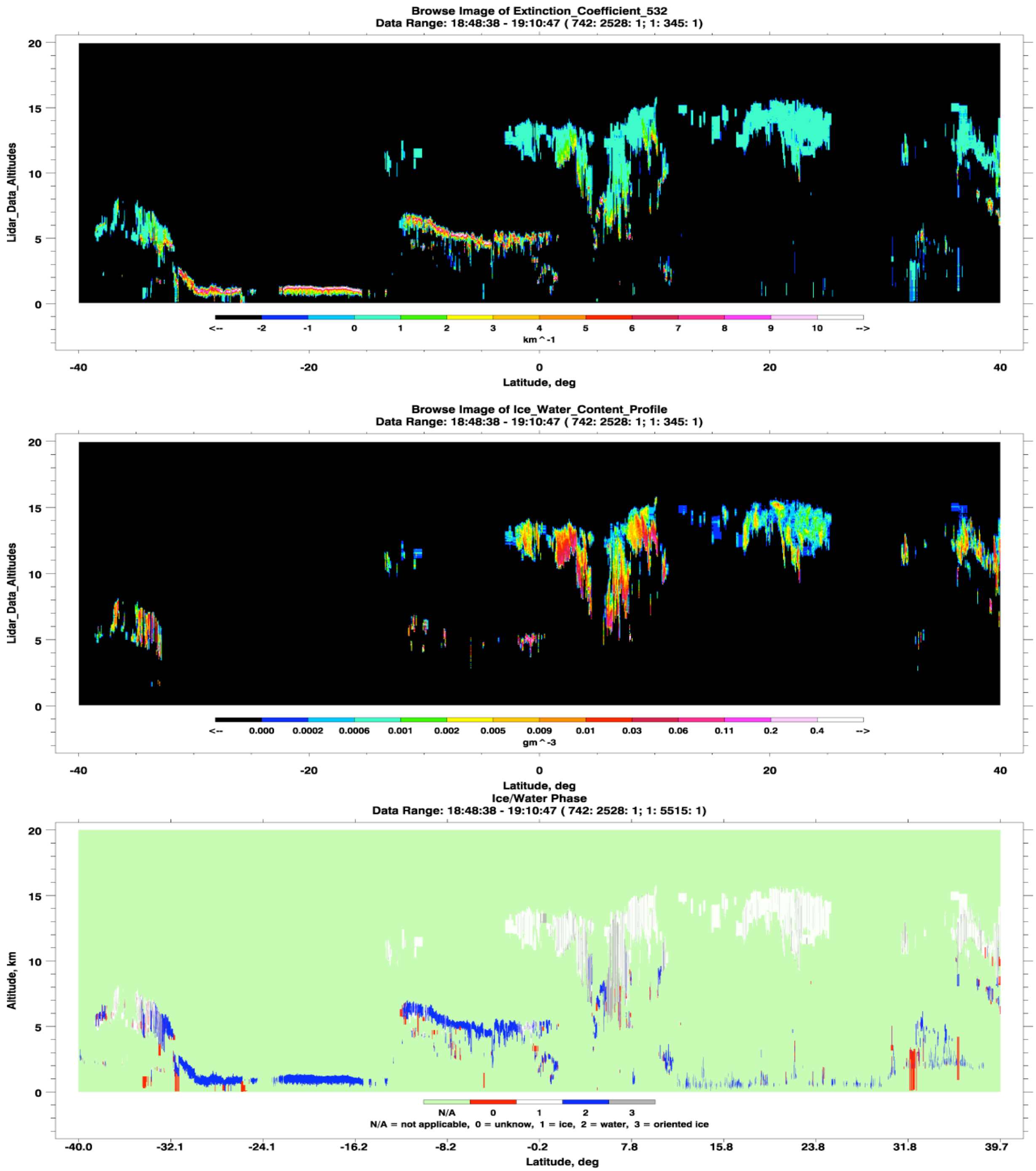

Figure 2. CALIOP images of 532 nm extinction coefficients (km^{-1}), IWC (gm^{-3}) and ice/water phase measured on Aug. 5, 2007.

A comparison of the plots shows the relationship between the cloud extinction coefficient and IWC. Since the parameterization was developed for ice clouds only, IWC is not calculated for the low altitude water clouds occurring between 32°S and the equator. These images feature an actively developing convective cloud complex associated with the ITCZ between 3°S and 10°N. This cloud includes both randomly-oriented (ROI) and horizontally-oriented (HOI) ice cloud particles, which are distinguished by examining the depolarization ratio [7]. Accurate extinction retrievals are much more difficult for clouds containing HOI due to an anomalously low lidar ratio, but they are included in the beta data release for evaluation. The HOI in this image is located between 1°-4°N at altitudes between 4-8 km.

This CALIPSO overpass of Central America coincides with sampling of this cloud during the

NASA Tropical Composition, Clouds and Climate Coupling Experiment (TC[4]), thus providing extensive, independent *in situ* and remote measurements of cloud IWC from the DC-8, WB-57 and ER-2. *In situ* measurements of IWC from the ER-2 and the DC-8 (Avallone and Twohy, personal communication) show values of 0.0005-0.010 gm^{-3} between 14 and 16 km and 0.1-1.3 gm^{-3} between 8 and 11 km. These values suggest that the lidar-derived values are in the correct range or may be slightly low, even for HOI. Lower values might be expected for CALIOP IWC due to profile averaging during the lidar data analysis. However, the first look is very encouraging because CALIOP resolves the expected cloud morphology. Analysis of the lidar IWC precision is needed, and a comprehensive case study is currently underway.

3. PROBABILITY DISTRIBUTION OF IWC

The number of available data points is increased by a factor of 15 by including unconstrained extinction retrievals that do not require the extinction algorithm to adjust the lidar ratio. These clouds have a maximum optical depth of 8.5 and mean optical depth of 0.36, as opposed to a maximum of 5.8 and a mean of 0.96 for clouds with constrained solutions, so the data set is expanded to include both thicker clouds and a larger fraction of thinner clouds. Figure 3a shows CALIOP probability distributions calculated for August 2007 using only the constrained extinction retrievals (3M data points), compared with Figure 3b, which includes unconstrained retrievals (45M data points). Probability distributions are plotted at temperatures in the range -80° and 0° C, and both figures show peaks at small values of IWC (< 0.010 gm^{-3}) and at moderate temperatures (-60° to -40° C, colored green on the plots). The larger data set apparently includes a larger fraction of very small IWC measurements, which need to be evaluated for significance, since the lower limit for CALIOP IWC has yet to be determined. Upper limits for IWC based on the maximum retrievable extinction coefficients of 33 km^{-1} below 8.25 km and 16 km^{-1} above 8.25 km correspond to IWCs of 0.77 and 1.9 gm^{-3}, respectively. IWCs over 0.540 gm^{-3} represent only 0.5% of the data during August 2007, and measurements of 0.026 gm^{-3} or less are likely to be most reliable since they correspond to smaller retrieved extinction coefficients of < 1.0 km^{-1}.

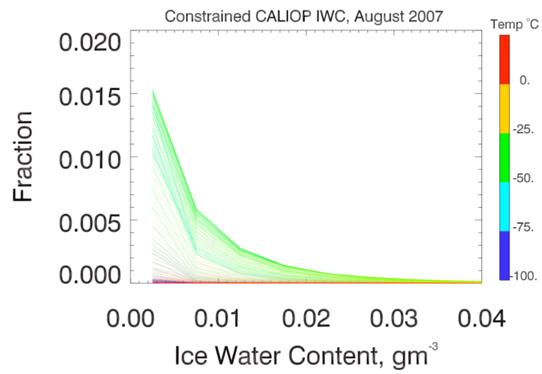

Figure 3a. CALIOP IWC probability distributions for August, 2007, for ROI, constrained retrievals only. Curves are colored by temperature. The distributions peak at temperatures between -40° and -50° C, plotted in green.

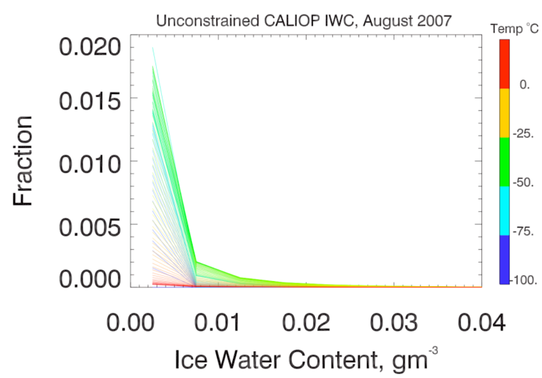

Figure 3b. Distributions are plotted as for Figure 3a, but here they include unconstrained extinction coefficient retrievals that use a tabulated lidar ratio for the cloud type.

Since retrievals of extinction coefficient in clouds containing HOI are more challenging, evaluation of the associated IWC is necessary. Figure 4 shows a plot of the 2-D probability distribution of HOI. It is clear that with HOI there is a larger fraction of large IWC values (> 0.1 gm^{-3}) than for the constrained ROI shown in Figure 1. This is because HOI tends to occur at lower altitudes and temperatures that favor larger IWC, but also may represent an artifact of the difficulty of specifying the correct lidar ratio for the extinction retrievals in these clouds, so care must be used in interpreting these results. HOI is identified separately from ROI (and also water clouds) using a cloud phase flag in Version 3 data.

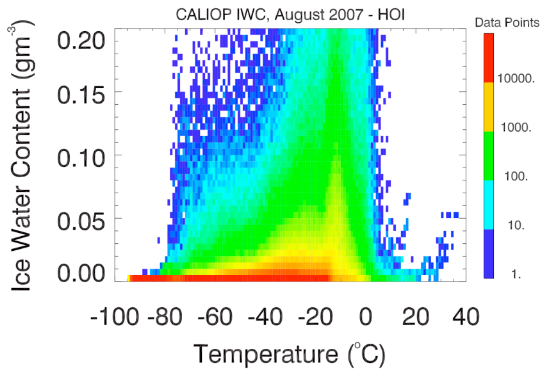

Figure 4. Probability distribution of IWC and temperature for August 2007, for horizontally-oriented ice particles.

4. IWC FRACTIONAL UNCERTAINTY

The fractional uncertainty of IWC is a simple multiple of the extinction coefficient fractional uncertainty, and validation of IWC accuracy is also useful for extinction coefficient validation. A plot of the frequency of fractional uncertainties of IWC during August 2007 is shown as Figure 5. This plot shows that CALIOP IWC can have an intrinsically large fractional error due to the difficulty in retrieving extinction coefficients under some atmospheric conditions.

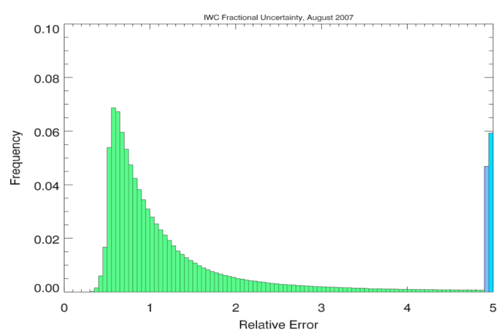

Figure 5. IWC fractional uncertainty for August 2007. Green bars are valid uncertainties up to 500%. The darker blue bar represents unsuccessful extinction retrievals, set to a fill value of 99.9. The light blue bar represents large fractional uncertainties, which can occur for small IWC.

Cumulative overhead optical depth above a layer also directly impacts the accuracy of extinction coefficient retrievals, through fractional errors that propagate as calibration errors. Because the IWC values are calculated from the extinction coefficients, it is critical to consider the integrated overhead optical depth when evaluating the accuracy of CALIOP IWC.

5. SUMMARY

The new CALIOP high-resolution IWC data product shows a great deal of promise in providing IWC measurements with sufficient resolution and sensitivity to resolve internal cloud structure, and therefore can become a valuable tool for linking cloud micro- and macrophysical properties. The data are provided at 60-m vertical resolution in the 5-km cloud profile data set.

Currently the CALIOP IWC data release is in a beta stage, with preliminary evaluation and comparisons underway. Current evaluation includes a detailed case study during the NASA TC^4 experiment. Comparisons with CLOUDSAT and MLS are also underway. A first look at the data suggests that the values are physically realistic, and may provide unique information about IWC.

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